Operative Classification of Brain Arteriovenous Malformations

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The first description of brain arteriovenous malformations (AVMs) can be found in the observations of Luschka [1] and Virchow [2] in the mid 19th century: they were generally categorized as vascular hamartomas. It is believed that the majority of these lesions are congenital in origin, arising between three and eight weeks of gestation [3-5]. Morphologically, they resemble the normal anastomotic plexuses formed during the early embryogenesis of the brain vascular system. Several recent studies have revealed possible factors involved in the formation and pathogenesis of AVMs. In particular, the gene that results in the production of endothelin-1, the potent vasoconstrictor agent involved in vascular cell growth, has been found to be repressed in cerebral AVMs; this may be the possible cause of the abnormal autoregulation found in AVMs [6].

Other agents, implicated in angiogenesis and endothelial proliferation, like the vascular endothelial growth factor, have been shown to increase and be potentially involved in the pathogenesis of AVMs [7]. AVMs usually occur in sporadic fashion in approximately 0.5-1% of the population (about 1/10 the frequency of intracranial arterial aneurysms) [6,8].

They are direct connections of one or more arteries to one or more draining veins, without an intervening capillary bed with three major components: arterial feeders, nidus and venous drainage; the association with aneurysms is well documented, occurring between 6% and 20% of patients [4,9-11].

As knowledge regarding AVMs has progressed, classification systems have been proposed and refined [12,13].

Brain arteriovenous malformations are complex pathologies. Not only the origin of these lesions but also the pathophysiological significance of morphological factors is not fully understood today. In addition, the term brain AVM is commonly used to subsume different types of AV-shunting vascular brain pathologies. This complexity makes it difficult to understand or predict natural history and even more difficult to assess a therapeutic risk.

This complexity underlines the need for a "clear" classification that would be simple enough to be used worldwide and comprehensive enough to represent the full complexity of these lesions.

Classification systems of any medical disorder enhance and standardise communication, may provide insight into pathophysiology and assist in developing and controlling therapeutic strategies. To become universally accepted, a proposed classification should include estab-

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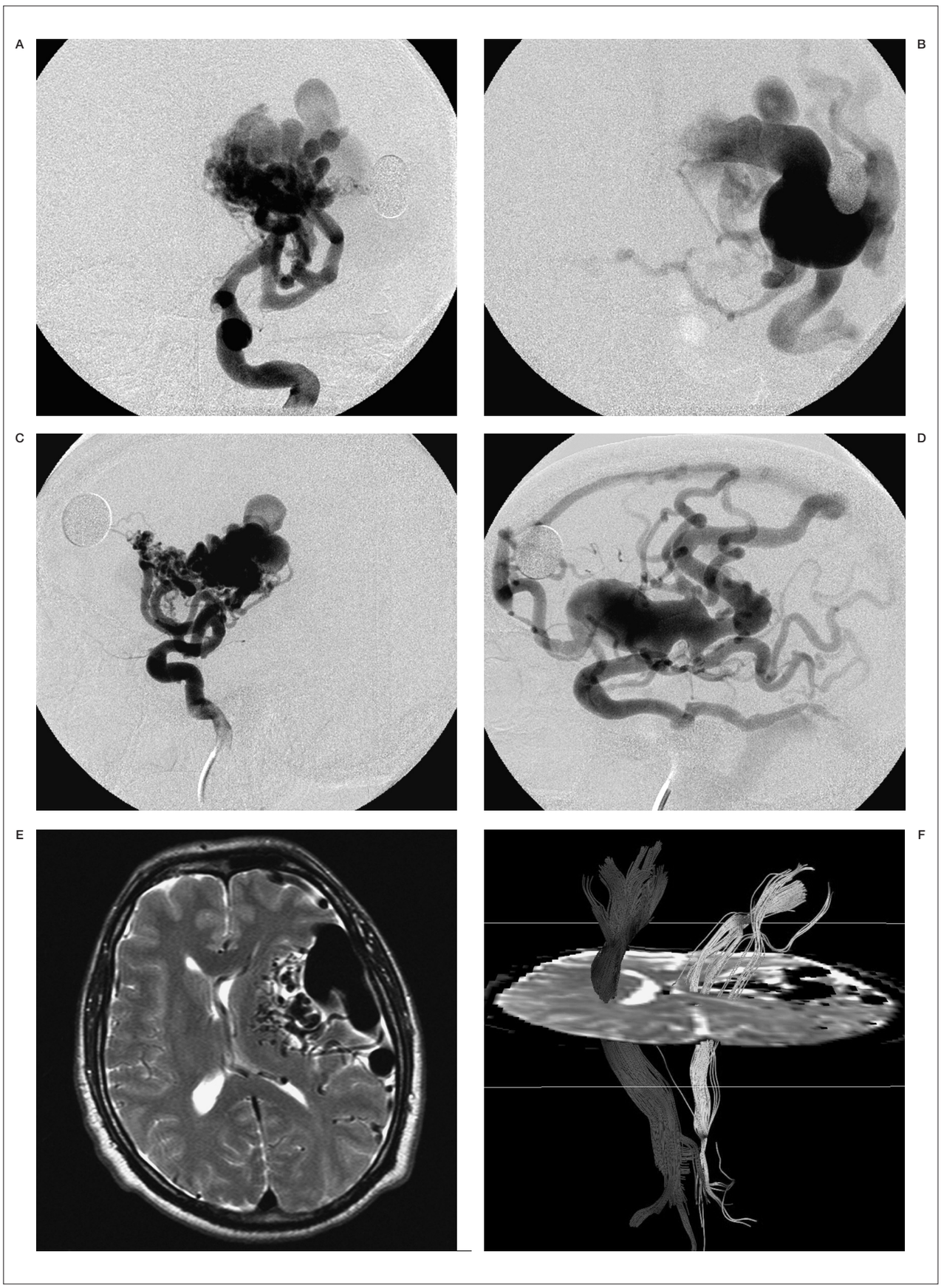
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lished data, remain logical and convey information clearly.

Classification systems of AVMs have considered angioarchitectural features including size, location, number and distribution of feeding vessels, pattern of venous drainage, flow and the amount of blood steal from the surrounding brain [14-16].

Modern DSA and MR techniques permit a better delineation of a given AVM, resulting in a more accurate classification (figures 1 and 2).

Numerous grading schemes have been proposed based on the characteristics of a given AVM, in an attempt to determine the associated risk of bleeding [17]. However, the available classifications are so different that comparisons between various series are extremely difficult. It is important to note that this risk is twofold: one must consider both the risk associated with the natural history and the specific features of a patient with an individual AVM and the risk associated with the specific morphology of that given AVM. After weighing up these factors, the specialist can recommend the best treatment option (surgical, endovascular or radiosurgical) to the patient, tailored to his case.

As far as natural history is concerned, intracranial haemorrhage is the most feared and common presentation (65% of cases) [18] to be faced in the management of the patient. To sum up, the risk for intracranial hemorrhage due to an AVM is about 3% per year [19,20] with a mortality and major morbidity rate of less than 30%. Other authors report lower morbidity/mortality rates [21]; the lifetime calculated risk of haemorrhage is 105 minus the patient's age in years [22].

According to most authors features predicting haemorrhage are a history of bleeding [19,23-26] and a series of angioarchitectural patterns: a single draining vein [10,27,28], especially if deep [26,29,30] (basal ganglia and posterior fossa); diffuse AVM nidus [10]; the recognition of intranidal aneurysms [31,32] and arterial supply via perforators [33].

In our institution, we use a so-called brain AVM Cumulative Score, made up of the sum of

Figure 1 Left temporal-insular AVM. A,B) Digital subtraction angiography. Early and late anteroposterior view. C,D) Lateral view. E) T2 weighted axial MR scan. F) Similar T2 weighted section with Diffusion Tensor Tractography superimposition demonstrating the displacement and dispersion of the left corticospinal tract (green) by the AVM. Right corticospinal tract (brown) is normal.

Table 1A,B **Brain AVMs intention to treat score (ITS: 0-12)**

A) Patient Features (0-6)

		Score
Age (yrs)	>65 >50 <65 <50	2 1 0
Previous Hemorrhages	No Yes	2 0
Neurological Deficits	No Yes	1 0
Patient's Firm Intention to be Treated	No Yes	1 0

B) AVM Characteristics (0-6)

		Score
Small Size	No Yes	1 0
Deep Brain Location	No Yes	1 0
Exclusive Deep Venous Drainage	No Yes	2 0
Associated Aneurysm/Varix	No Yes	2 0

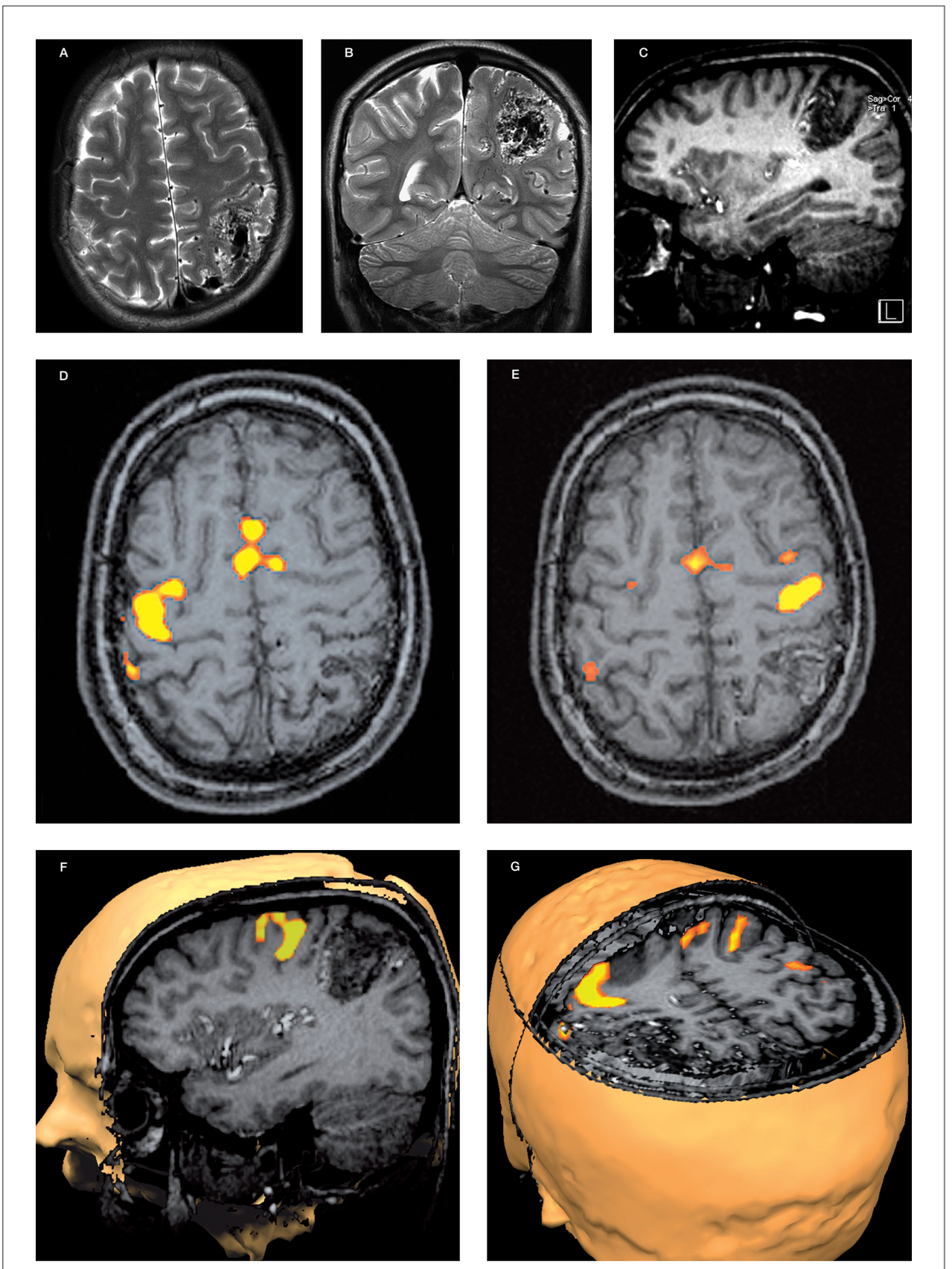
Table 2 **Brain AVMs treated in the Department of Neurosurgery of Verona (period 2000-2006).**

Treatment Modality	**N° of Patients**	**Percentage of Total**
Direct radiosurgery	179	56%
Direct surgery	23	7%
Combined treatment *	115	37%
Total	317	

**endovascular treatment alone or in association with radiosurgery or surgery*

Table 3 **Spetzler and Martin Surgical risk grading system** (reproduced from J Neurosurg 65: 476-483, 1986).

AVM Features		**Score**
Size cm	Small (<3 cm) Medium (>3 <6 cm) Large (>6 cm)	1 2 3
Eloquence of Adjacent Brain	Non eloquent Eloquent	0 1
Pattern of venous drainage	Superficial only Deep	0 1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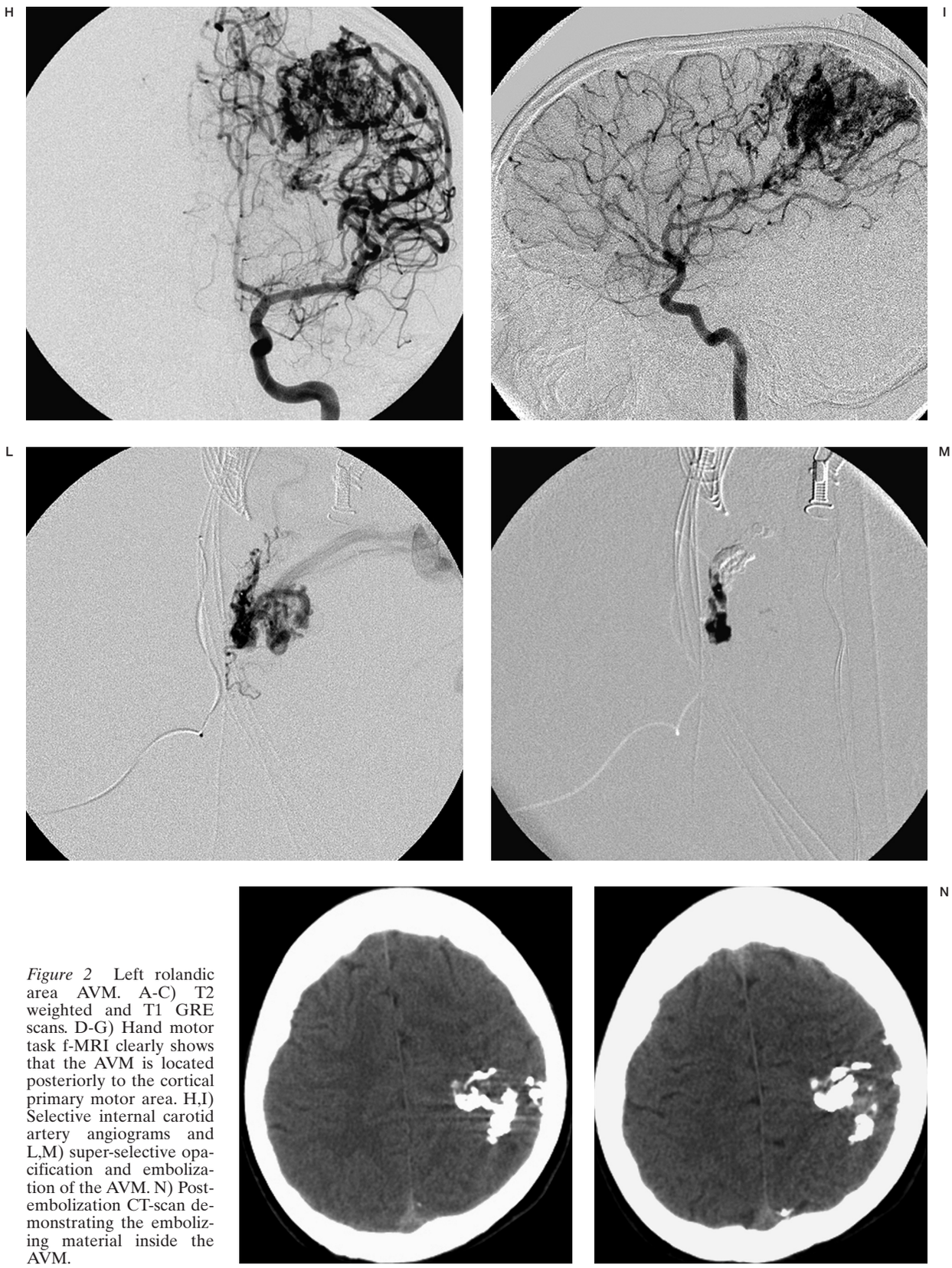

Figure 2 Left rolandic area AVM. A-C) T2 weighted and T1 GRE scans. D-G) Hand motor task f-MRI clearly shows that the AVM is located posteriorly to the cortical primary motor area. H,I) Selective internal carotid artery angiograms and L,M) super-selective opacification and embolization of the AVM. N) Post-embolization CT-scan demonstrating the embolizing material inside the AVM.

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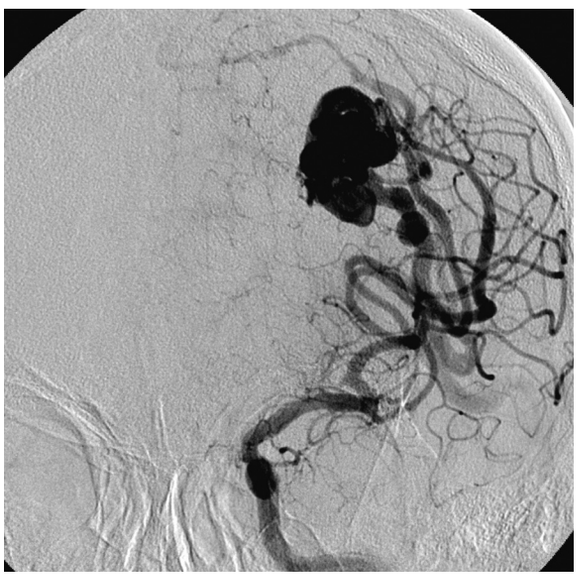

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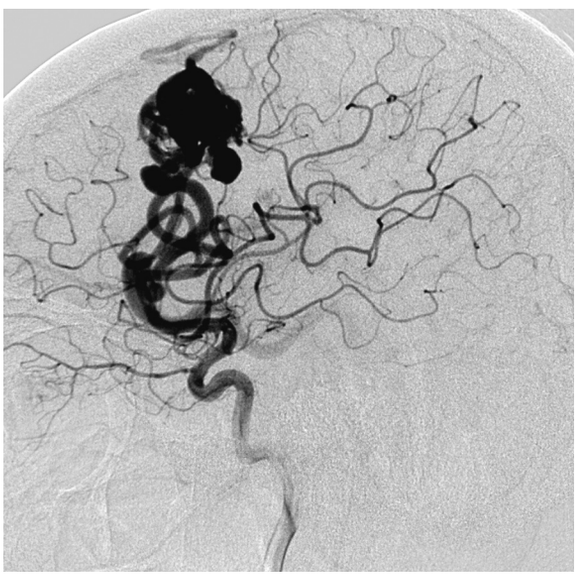

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ITS

PATIENT FEATURES		Score
Age (yrs)	>50 <65	1
Previous Hemorrhage	yes	0
Neurological Deficits	no	1
Firm Patient Willing	yes	0
		2

AVM CHARACTERISTICS		Score
Small Size	<10 cm^3	0
Deep Brain Location	no	1
Exclusive Deep Venous Drainage	no	2
Associated Aneurysm/Varix	no	2
		5

ITS: 7

TRS

Surgery		Score
Size	Small	1
Eloquence of Adjacent Brain	yes	1
Pattern of Venous Drainage	Superficial Only	0
		2

Radiosurgery		Score
Volume	>5 <10cm^3	2
		2
Embolization		
Volume cm3	<10	1
Eloquence	yes	1
Perforators	no	1
		2

CS: ITS 7 + TRS 2 = 9 ⟶ Treament recommended

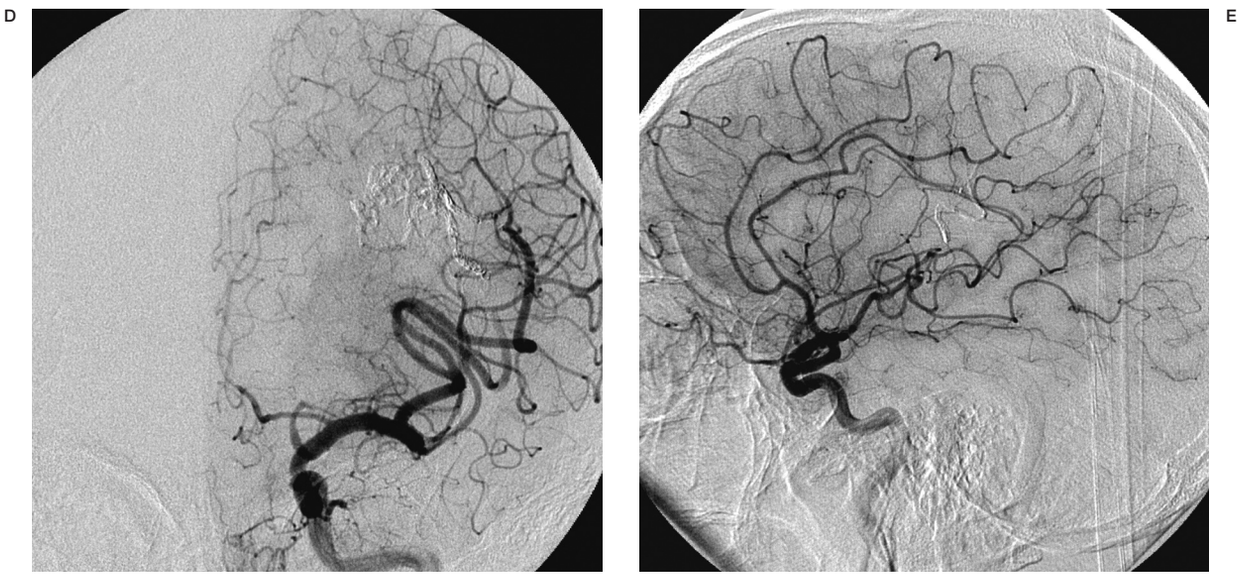

Figure 3 60-year-old male: left frontal hemorrhage with aphasia. A,B) Antero-posterior and lateral DSA showing a left prerolandic AVM with a 9 cm^3 approximate volume. Feeders are coming from pre-fontal and pre-central branches of the MCA. Venous drainage is superficial. C) ITS, TRS and CS scores for this patient. D,E) Anteroposterior and lateral post-embolization DSA.

an Intention to Treat Score (ITS) and Treatment Risk Score (TRS). Even though these scores combine morphological AVM features with clinical/physiological factors, their use can be justified by the achievement of a single simple score, the "core" of the process of decision-making of the single patient (treatment or abstention, type of treatment).

"Intention to Treat Score (ITS) " is made up of the sum of scores deriving from patient features and AVM characteristics. patient features are: age (>65 yrs: 2; >50 <65 yrs: 1; <50 yrs: 0); history of a hemorrhage (no: 2; yes: 0); neurologic deficits not related to a previous haemorrhage (no: 1; yes: 0); patient's firm intention to be treated, important from a psychological point of view (no: 1; yes: 0). avm characteristics are: small size, volume less than 10 ml (no: 1; yes: 0); deep brain location (no: 1; yes: 0); exclusive deep venous drainage (no: 2; yes: 0); associated aneurysm or varix (no: 2; yes: 0) (Table 1).

From the total of patient score (0 - 6) and avm characteristics score (0 - 6), the ITS is calculated, ranging from 0 to 12.

In our Department the decision on which option (surgery, radiosurgery, embolization orvery frequently-combined treatments) would be best for the patient, is made after assessment by all the members of the AVM team

Table 4 **Brain AVMs Treatment Risk Score (TRS: 1-5). A) Surgery, B) Radiosurgery, C) Embolization**

	Grade	Score
Spetzler-Martin Modified	I	1
	II	2
	III	3
	IV	4
	V	5

Volume cm^3	Score
< 5	1
> 5 < 10	2
> 10 < 20	3
> 20 < 30	4
> 30	5
One point minus if low flow	

		Score
Volume cm^3	< 10 > 10	1 2
Eloquence	No Yes	0 1
Perforators	No Yes	0 1
Unfavorable Angio-architecture	No Yes	0 1

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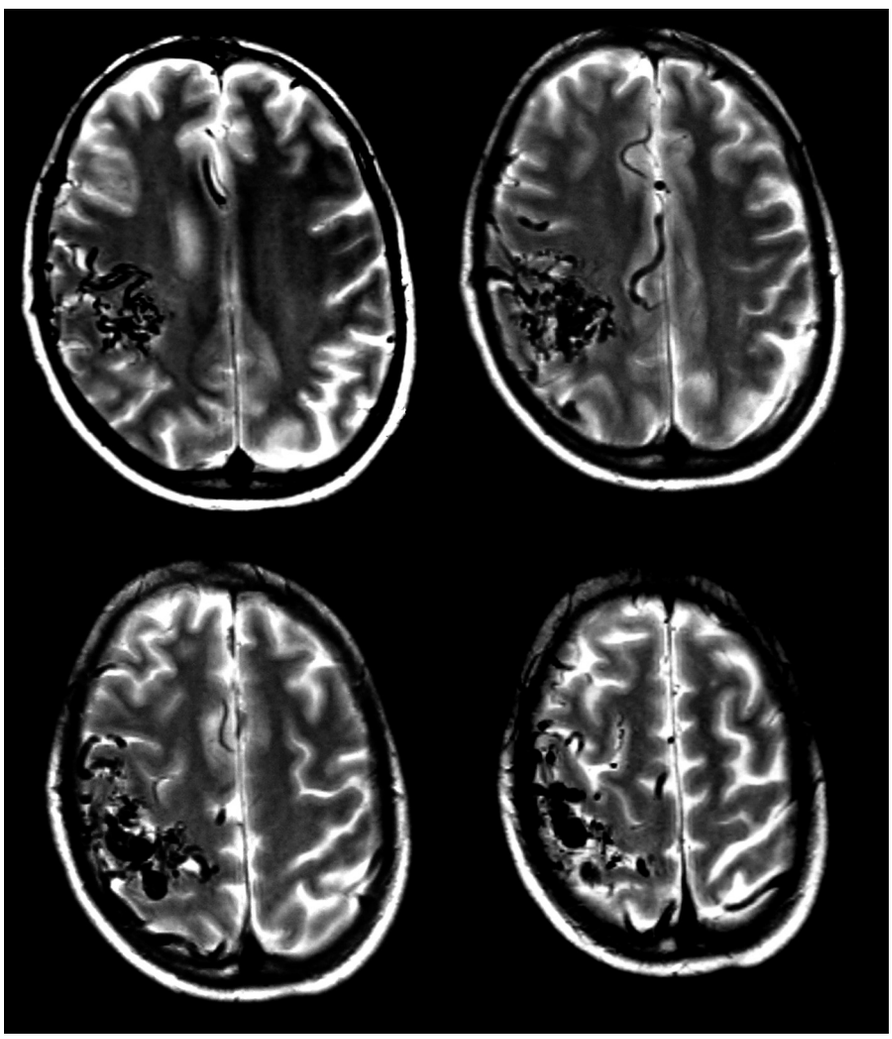

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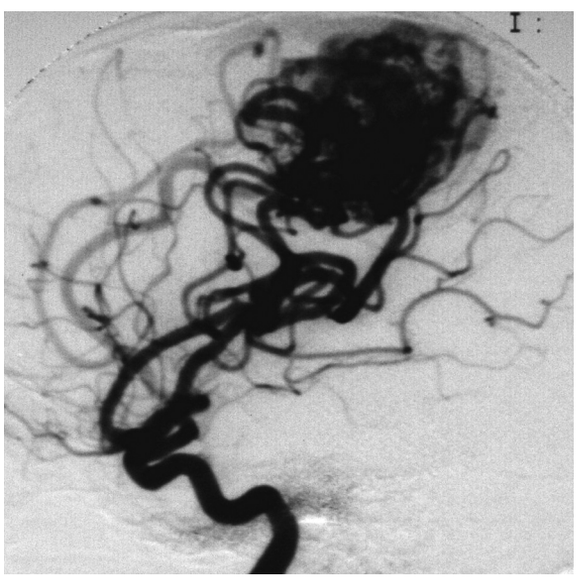

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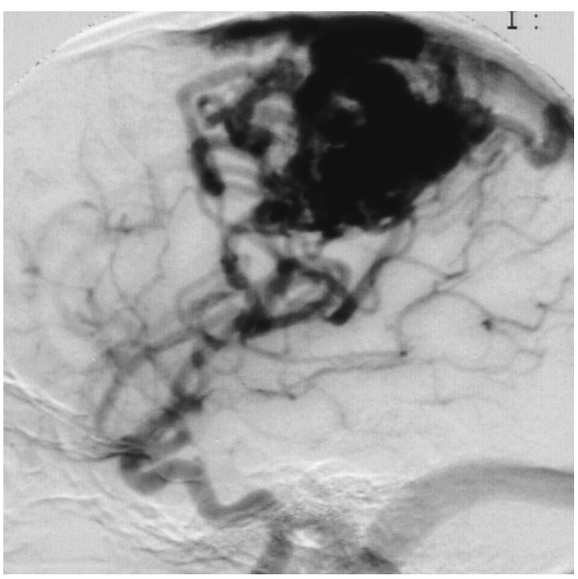

Figure 4 42-year-old male without previously known bleeding. Axial T2-weighted images (A) and early (B) and late (C) phase lateral DSA showing a right rolandic AVM with a 21 cm^3 approximate volume. Feeders are coming from cortical ACA and MCA branches and venous drainage is superficial. D) ITS, TRS and CS scores for this patient. E) DSA after embolization (5 procedures) and radiosurgery.

D

ITS

PATIENT FEATURES		Score
Age (yrs)	< 50	0
Previous Hemorrhage	no	2
Neurological Deficits	no	1
Firm Patient Willing	yes	0
		3

AVM CHARACTERISTICS		Score
Small Size	no	1
Deep Brain Location	no	1
Exclusive Deep Venous Drainage	no	2
Associated Aneurysm/Varix	no	2
		6

ITS: 9

TRS

Surgery		Score
Size	Medium	2
Eloquence of Adjacent Brain	yes	1
Pattern of Venous Drainage	Superficial Only	0
		3

Radiosurgery		Score
Volume	> 20 < 30 cm^3	4
		4
Embolization		
Volume cm^3	> 10 > 20	2
Eloquence	yes	1
Perforators	no	0
		3

CS: ITS 9 + TRS 3 = 12 ⟶ Treament recommended with significant risk

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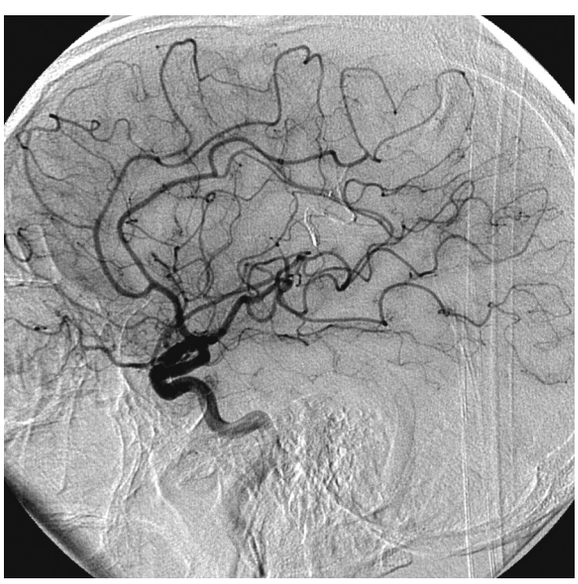

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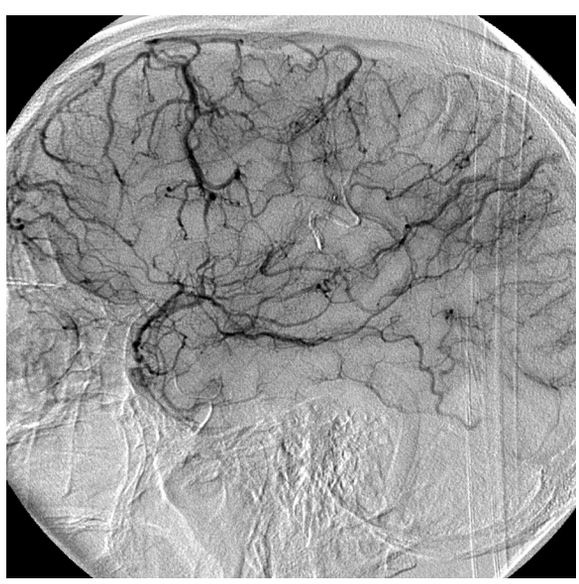

Table 5 **Brain AVMs Cumulative Score (CS = 1-17: ITS (0-12) + TRS (1-5)) and recommended strategy.**

1 - 10 Treatment recommended
11 - 12 Treatment offered with significant risk
13 - 17 Treatment not recommended

considering also the patient's preference (of no less importance) (Table 2).

For each brain AVM to be treated, a "Treatment Risk Score (TRS)" ranging from 0 to 5 is calculated, irrespective of the choice of surgery, radiosurgery or embolization.

The most popular grading scheme for predicting surgical risk is the system described by Spetzler and Martin in 1986 [34] which divides patients into five risk categories on the basis of three AVM features: size (1-3), eloquence of location (0,1) and pattern of venous drainage (0,1) (Table 3). The grade of any particular lesion is the sum of its score for each of these three characteristics, ranging from grade I (simplest and lowest risk) to grade V (most complex and highest risk). Using this classification, permanent morbidity and mortality ranged from 0 for patients with grade I AVMs to 17% for grade V AVMs [35].

In our Department the Spetzler-Martin classification is used, with the variation that grade III AVMs with the presence of lenticulo-striate arterial supply (gr. III b AVMS) are scored IV as grade IV AVMs (Table 4A), due to the demonstrated increased risk of surgical complications associated with the presence of perforators feeding the AVM [34].

Like the grading scheme of Spetzler and Martin, by far the most popular and widely accepted, we propose two other grading schemes scoring 1 – 5 both for radiosurgery and embolization, respectively.

The main feature in predicting radiosurgical risk both for radionecrosis and/or failure of treatment is the volume of the AVM nidus. On the other hand, in our experience, based on more than 250 treated AVMs [36,37], reduced nidal flow (both spontaneous or decreased by embolization) is associated with a higher post-RS obliteration rate, also occurring in a shorter time. Analyzing the results of our personal experience, we assigned a higher score to larger volume AVMs (<5 cm^3: 1; >5 <10 cm^3: 2; >10 <20 cm^3: 3; >20 <30 cm^3: 4; >30 cm^3: 5). One point is subtracted if the AVM has a low flow (for example: a 13 cm^3 AVM is scored 2 – not 3 – if it is a low-flow AVM) (Table 4B).

In our experience [33], the four main factors predicting embolization risk are: volume (<10 cm^3: 1; >10 <20 cm^3: 2; >20 cm^3: 3), eloquence (not eloquent: 0; eloquent: 1) and the presence of perforators as feeders (no perforators: 0; perforators: 1) and the presence of "unfavourable" angio-architecture such as very loopy arteries in the neck or "comb vessels" as feeders (unfavourable 0; favourable: 1) (Table 4C).

The Cumulative Score (CS) is calculated from the total of ITS (0-12) and TRS (1-5) scores: according to this, with a score from 1 to 10, treatment is strongly recommended, with 11 to 12 treatment is offered but with a significant risk and with 13 to 17 no treatment is recommended (Table 5).

The use of this simple operative classification is of great assistance to our team (endovascular-surgical-radiosurgical) in decision-making regarding treatment and, above all, results with improved patient counselling (figures 3,4).

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